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Optimal information output in urban traffic scenarios: an evaluation of different HMI concepts

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Abstract

A new HMI concept for urban driving consisting of the in-vehicle components Head-Up Display, the Instrument Cluster and the Acceleration Force Feedback Pedalis used in this paper to inform and warn the driver with visual and haptic feedback. Different Advanced Driver Assistant Systems, like a traffic sign assistant and a speed assistant, are embedded in this concept. The study shows great potential in the operation of an integrative HMI concept for the above-mentioned ADAS in urban areas. While the workload remains the same, even with additional information and warnings for the driver, several advantages exist, such as maintaining the speed limit or driving economically efficient. The results will help to further develop this HMI concept, while maintaining the need to be able to drive safely and efficiently in urban areas.

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1. Motivation

The traffic in urban areas is characterized by its high complexity resulting from a variety of different road users, high number of static and dynamic objects like traffic signs, and a high density of information [4]. In the context of the collaborative research project UR:BAN (Urban Space: User oriented Assistance systems and Network management), which started in 2012 [5], new, innovative and intelligent Advanced Driver Assistance Systems (ADAS) have been developed to assist the driver with the driving task in urban environments. For a suitable

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assistance, the interaction between user and system must allow effortless and uncomplicated interaction between the two parties.

A first concept, only consisting of the Head-Up Display (HUD) and the Instrument Cluster (IC), to evaluate different warning and information strategies, was conducted in a static driving simulator. The study found a significant lower workload for warnings, traffic sign recognition and speed, presented in the HUD [6]. In subsequent work, an HMI concept was devised to assist the driver to drive safely and economically efficient, with minimal workload, in an urban area. This concept was again composed of the components HUD and the IC and in addition with the Accelerator Force Feedback Pedal (AFFP) as haptic component [3]. The benefits of these three components as well as the qualitative and quantitative requirements were published earlier [1]. On the basis of these two studies, this experiment was executed, developing and evaluating an overall generic and integrative HMI concept.

2. Method

2.1. Components

2.1.1. Head-Up Display

The HUD is a visual component, which projects a virtual image in the windshield of the vehicle. The virtual image is displayed between two and three meters in front of the driver. Many advantages of HUDs are already researched [11, 12, 13]. For example, the use of an HUD will help to maintain the allowed speed significantly better [14] and react faster to warnings [19]. The physical side allows the driver to maintain 40% - 50% visual acuity on the street or driving scenery while reading the HUD (compared to only about 10% when reading the IC) [15].

2.1.2. Instrument Cluster

The Instrument Cluster is the primary in-vehicle output component to transmit all types of driving-related information in line of the driver's view [16]. It developed into a digital version called free programmable Instrument Cluster. At first, a small display between the two analogue gauges displayed the increasing amount of information [17]. Such a display was able to present additional none driving-related information like the mileage, service intervals, or fuel consumption [18]. With an increasing amount of ADAS, the IC as complete digital display is used to display demand-oriented warnings or information.

2.1.3. Accelerator Force Feedback Pedal

Transmitting information about the vehicle speed or acceleration is very suitable for the Accelerator Force Feedback Pedal, as it intervenes with the vehicle's longitudinal dynamics [10]. The AFFP can give haptic feedback to the driver like counter-pressure, vibration, or slight double twitches or pressure [3]. The main task is helping the driver with the longitudinal guidance and keeping him in the loop [7]. It is usually used to transmit information for economical driving (e.g. traffic light assistant) but can be used for warning scenarios as well.

2.2. Experimental design

Only Advanced Driver Assistance Systems in the longitudinal direction were implemented. The focus of the study were non-intervening systems without taking over the driving task. These include a speed assistant, a traffic light assistant, and a vehicle distance assistant. Additionally, an emergency brake system was installed.

The conducted study evaluated the concept in a static driving simulator. The HMI concept was implemented with the simulation software SILAB [9]. An urban driving track was created to simulate ordinary city driving scenarios.

2.3. HMI concept

As mentioned before, the overall concept consisted of the HUD, the IC and the AFFP. The Head-Up Display was divided into three different clusters (see Figure 1). The left part showed the current speed (digital) and the speed limit. Using the law of proximity here, reduces the coding effort for the driver. The central part was used to show

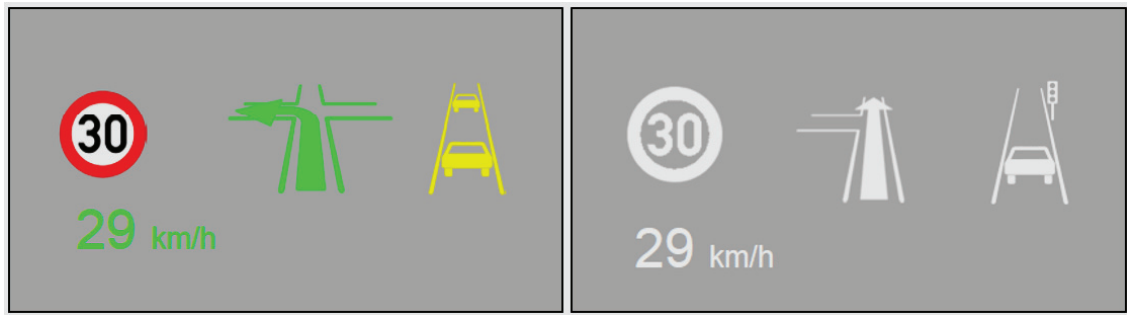


Fig.1.Cluster of the Head-Up Display in the colored version (left) and monochrome version (right).

navigation information. The last part on the right was reserved for driving assistance systems. Moreover, a colored and a monochrome version of the HUD concept was used to compare possible differences.

The instrument cluster was used to display driving-relevant, non-time-critical information. Both gauges, for speed and the rev counter were kept untouched. Warnings and information of ADAS were displayed in the space between those two. Additionally, a small green arrow in the speedometer indicated the best speed to comply with assistance systems like the traffic light assistant.

Finally, the AFFP transmitted a noticeable counter-pressure to the driver and an adjustable pressure threshold. Using this threshold helped the driver to maintain the allowed speed or keeping the distance to a vehicle ahead.

If one of the assistance system was activated, a symbol in the HUD and IC informed the driver. At the same time, the AFFP was activated and gave an additional haptic feedback. The HUD symbol vanished after three seconds, to keep the visual workload low. When needed, the driver could get the information from the IC. All symbols were kept very generic, just with different regulator objects such as the traffic light or the vehicle ahead (see Figure 2).

2.3.1. Speed assistant

The speed assistant helped the driver to maintain the allowed maximum speed or, with the help of counter-pressure through the AFFP, lowering the current speed. The main advantage of this system is the haptic feedback of the AFFP where eyes can be kept on the road [8]. In addition to the haptic feedback, a road sign with the allowed maximum speed (cf. Figure 1) was displayed in the HUD. Exceeding the allowed speed by at least 5 km/h displayed an additional small text information ("Speed Limit") in the instrument cluster.

2.3.2. Traffic light assistant

The traffic light assistant was used to reduce possible downtimes in front of a traffic light, to indicate the "perfect" speed to cross the traffic light, and to inform the driver if he definitely has to stop at the next light. This is among other things suitable for CO₂ efficient anticipative driving. The assistance system followed the rules of the road (StVO).



Fig.2.The HMI concept of the instrument cluster with the three different generic symbols. Traffic light assistant (left), distance assistant (centre), and both active (right).

The process of information presentation applied is similar to the speed assistant. First, a haptic feedback from the AFFP informed the driver to lower his speed to a certain point. Additionally, a symbol was presented in the right cluster of the HUD and the same symbol in the middle of the IC. Again, the symbol in the HUD vanished after three seconds while the symbol in the IC stayed as long as the system was active. Furthermore, a small green arrow in the speedometer displayed the target speed. If no action was required for the driver to pass the next traffic light, the traffic light assistant was not activated.

2.3.3. Vehicle distance assistant

The vehicle distance assistant was used to help the driver not fall below a specific distance or to maintain distance to the vehicle ahead. A distance in time of 1.2 seconds in this urban scenario was chosen. Once again, the assistance system transmitted haptic feedback to the driver with the AFFP and displayed a generic symbol in the HUD and IC. The display duration of both symbols were the same as in the ADAS mentioned before.

2.3.4. Emergency brake assistant

The emergency brake assistant tried to recognize potentially critical situations with an object in front of the vehicle, when the driver has to brake or will not be able to do it by himself. Falling below a certain distance (0.8 seconds) a (yellow) generic warning will pop up in the HUD and IC, to inform the driver. The next warning will pop up in the range of 1.5 s – 2.5 s TTC (according to [1]). The information will be more specific with a red warning symbol with the request to “BRAKE”. In absence of the required action of the driver and falling below 0.9 s TTC, the warning assistant will be activated as a next step. The system will take over the task of driving and execute emergency braking since the remaining TTC is too short for the driver. Generic information will be displayed again in both visual components in the vehicle. After emergency braking, when the critical situation is over, a green symbol will request the driver to take over again and to get back into the loop.

2.4. Procedure

Each participant had to perform an urban driving task. All had to drive two blocks on different courses in 30 min each after a 15 min training session. Participants operated either with all the ADAS available (displayed on the HUD, IC, and the AFFP) or just with the speedometer and a navigation system as baseline. Half of the sample used the monochrome HUD concept and the other half the colored one. After completion of each course, participants had to fill out questionnaires to compare the different experiences. All characteristics of the experiment were randomized amongst the subjects.

2.5. Objective and subjective data

The simulation software recorded all kinds of objective driving data, like speed, acceleration, time, RT, lane keeping accuracy, and so on. This data is used to analyze and evaluate the different assistant systems.

In addition to the objective data, the standardized NASA Task Load Index (NASA-TLX) [9] and a self-designed questionnaire was used. The NASA-TLX is used to compare the Overall Workload Index (OWI) of different tasks. On six different topics, participants rated the load on a scale from 0 to 100 in steps of 5 with 100 as the highest workload.

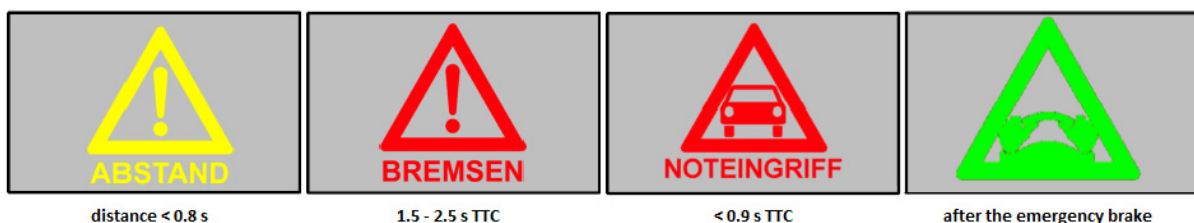


Fig.3. The different HUD pop-ups of the emergency brake assistant with different presentation timings and the text: “distance” (yellow), “brake” (left red), and “emergency intervention” (right red).

3. Results

For the analysis of the data, the objective and subjective data were compared between the baseline (no ADAS) and the assistant system one. Statistical t-tests were performed to examine differences in the reaction time, down times, velocity, and workload.

3.1. Participants

Thirty-eight healthy volunteers participated in the study (4 women, 34 men). The participants were between 20 and 53 years of age ($M = 27.4$, $SD = 5.2$). Twenty of them used a driving simulator for the first time. The Head-Up Display was a new HMI component for 16 of the participants.

3.2. Subjective analysis

The NASA-TLX questionnaire showed no significant difference between the workload of driving with ($M = 35$, $SD = 15$) and without ($M = 37$, $SD = 14$) additional ADAS.

Comparing the six different sub-scales, a significant difference was found for the physical demand between the workload with ADAS ($M = 21.8$, $SD = 18.3$) and the baseline ($M = 28.8$, $SD = 19.1$); $t(37) = 2.790$, $p < .01$. No significant difference was found for the mental demand, effort, frustration, temporal demand, and the performance.

3.3. Objective analysis – speed assistant

The percentage of time in which the participants exceeded the current speed limit by more than 5 km/h had a significant difference for track A ($M_{BASE} = 12.4\%$, $M_{ADAS} = 2.3\%$; $t_A(18.663) = -3.261$, $p_A = .004$) and track B ($M_{BASE} = 10.9\%$, $M_{ADAS} = 2.1\%$; $t_B(21.421) = -4.854$, $p_B < .001$).

Figure 5 shows a scenario where the speed is limited to 30 km/h for 500 m and increased to 50 km/h immediately after.

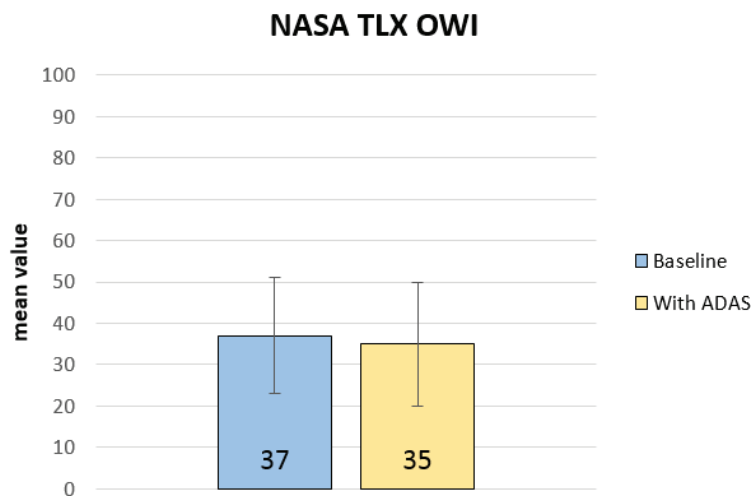


Fig.4. Subjective workload determined with the NASA-TLX score.

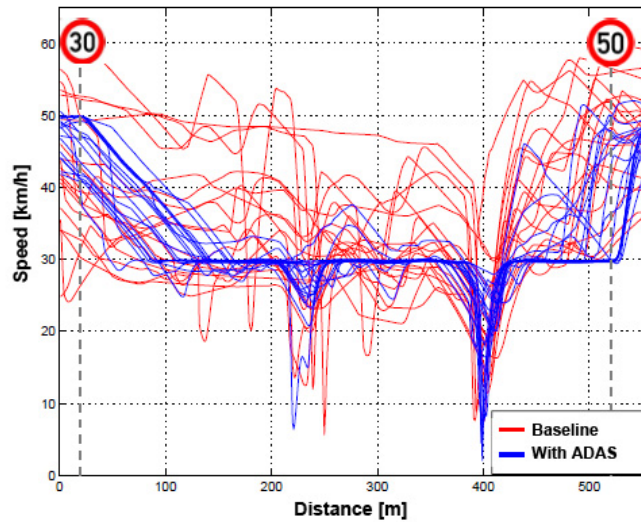


Fig.5. Velocity curve of all participants using either the speed assistant or no ADAS in an area with speed limit. The graph shows the average speed of all participants with active speed assistant (blue) and without (baseline; red).

The mean value for driving over the speed limit shows a trend towards significance for track A ($M_{BASE} = 20.6$ km/h, $M_{ADAS} = 16.6$ km/h; $t_A(34) = 1.742$, $p_A = .091$) and no significant difference for track B ($M_{BASE} = 15.1$ km/h, $M_{ADAS} = 12.6$ km/h; $t_B(33) = 1.043$, $p_B = .305$).

3.4. Objective analysis – traffic light assistant

The average speed loss while approaching a traffic light on a straight track was significantly higher without ADAS support ($M_{BASE} = 39.4$ km/h, $SD_{BASE} = 17.8$, $M_{ADAS} = 14.8$ km/h, $SD_{ADAS} = 4.2$; $t(20.388) = 5.6$, $p < .001$).

Figure 6 shows the average speed of all participants approaching a traffic light. The graph demonstrates the inefficient acceleration without a speed assistant system. Many participants without ADAS stopped the vehicle even though minimal reduction of the speed over time would reduce downtimes, fuel consumption and CO_2 .

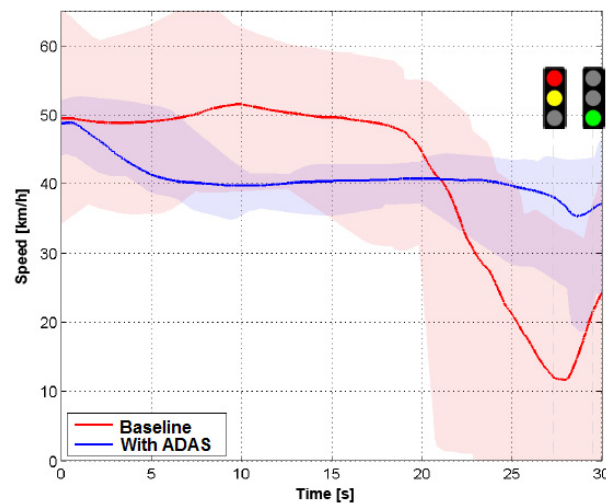


Fig.6. Average speed while approaching the traffic light (with speed range of all participants).

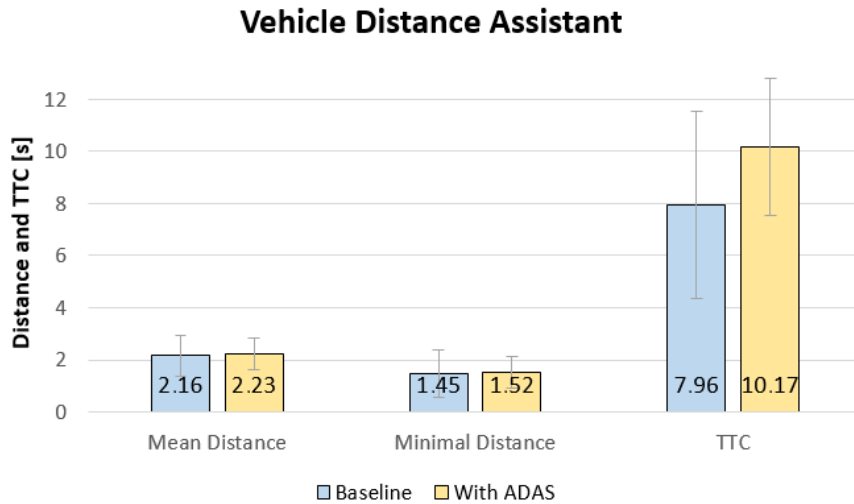


Fig.7. Mean and minimal distance as well as the TTC for the vehicle distance assistant.

Track A had nine traffic lights with three of them with other vehicles. Track B had seven traffic lights and three of them had additional vehicles waiting. Comparing the cumulated downtimes for each course shows no significant difference for course A ($M_{BASE} = 7.68$ s, $M_{ADAS} = 5.8$ s) but for course B ($M_{BASE} = 7.35$ s, $SD_{BASE} = 1.19$ s, $M_{ADAS} = 2.67$ s, $SD_{ADAS} = 1.06$ s; $t_B(31) = 2.919$, $p_B = .006$).

3.5. Objective analysis – vehicle distance assistant

The distance (in seconds) between the driver and the vehicle ahead was compared. No significant difference was found for the assistance in distance; $t(29) = -0.246$, $p = .807$. On the contrary, the graph of the baseline and the assisted driving were almost the same. On the other hand, comparing the shortest TTC of the baseline ($M_{BASE} = 7.96$ s, $SD_{BASE} = 3.59$ s) with the ADAS ($M_{ADAS} = 10.17$ s, $SD_{ADAS} = 2.65$ s) found a trend towards significance; $t(29) = -1.975$, $p = .58$. Figure 7 shows both values and the minimal distance compared between both variations.

3.6. Emergency brake assistant

The emergency brake assistant was used in four different scenarios: (1) vehicle ahead braking all of a sudden because of a crossing, (2) vehicle leaving a parking space straight in front of the driver, (3) vehicle ahead braking all of a sudden because of a parking space and (4) a car hidden behind a van taking the right of way.

No significant differences in the reaction time between the baseline and the assisted trial was found. All RTs with the SD of all four scenarios can be found in Tab. 1.

Table 1. RT of all four scenarios for the emergency brake assistant. No significant difference was found.

	Scenario (1)	Scenario (2)	Scenario (3)	Scenario (4)
Mean RT	$M_{BASE} = 1.04$ s ($\pm .15$)	$M_{BASE} = 1.37$ s ($\pm .24$)	$M_{BASE} = 1.46$ s ($\pm .43$)	$M_{BASE} = 1.68$ s ($\pm .25$)
	$M_{ADAS} = 1.06$ s ($\pm .23$)	$M_{ADAS} = 1.32$ s ($\pm .28$)	$M_{ADAS} = 1.40$ s ($\pm .27$)	$M_{ADAS} = 1.69$ s ($\pm .11$)

4. Discussion

All participants benefited from the HMI concept after a short familiarization period. This can be seen in the quality of maintaining the speed as well as the compliance with the traffic light assistant. Still, there are some factors to change or improve. The NASA-TLX showed no significant difference in workload and stress for the driver which

indicates that the additional visual stimuli and the haptic feedback did not distract the driver too much from his driving task. By using the overall concept, participants maintain the allowed speed significantly better. Additionally, the mean value for driving beyond the allowed speed trends towards significance as well. This helps to prevent accidents caused by speeding in the city. In addition, using the traffic light assistant resulted in a significantly lower speed losses approaching the crossing and significant lower cumulated downtimes. In the end, this will reduce fuel consumption and enhance CO₂ efficient driving. The vehicle distance assistant is the system, which needs further research and improvement. Its implementation in this study did not help the driver in a significant way to improve his driving experience. On the one hand, participants complained about the proposed distance being too short, and on the other hand, participants experienced the distances as being too big. The last assistance system, namely the emergency brake assistant, helped to prevent accidents but did not show any differences in RT. Although, this is helpful in reducing accidents, it is not due to the HMI concept, but rather the function itself. The chosen scenarios might have been too predictable or not foresighted enough to present realizable information and warnings.

In short, the study shows the great potential of an integrative HMI concept, operating the before mentioned ADAS in urban areas. While the workload remains the same even with additional information and warnings for the driver, several advantages exist, such as maintaining the speed limit or driving economically efficient. In a future study, information of additional assistance systems will be integrated into the overall HMI concept following the basic philosophy.

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